Executive Summary

For spaceflight applications, it is important to protect humans from unintended electrical current flow. These standards define the physiological limits for current flow for the following situations:

- Nominal – Under all situations
- Catastrophic hazard threshold for all conditions
- Catastrophic Hazard threshold specifically for Startle Reaction
- Leakage Current Designed for Human Contact.

Current thresholds were chosen (vs. voltage thresholds) because body impedance varies depending on conditions such as wet/dry, AC/DC, voltage level, large/small contact area, but current thresholds and physiological effects do not change. By addressing electrical thresholds, engineering teams are able to provide the appropriate hazard controls, usually through additional isolation (beyond the body's impedance), current limiters, and/or modifying the voltage levels. "Catastrophic hazard" language is used to relate the physiological level that shall not be exceeded without additional controls.

Relevant Standards

NASA-STD-3001 Volume 2, Rev C

[V2 9019] Nominal Physiological Electrical Current Limits
[V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances
[V2 9021] Catastrophic Physiological Electrical Current Limits for Startle Reaction
[V2 9022] Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds
[V2 9023] Leakage Currents – Equipment Designed for Human Contact

Body Impedance:
Guidance is provided in order to determine the appropriate body impedance for calculating the associated voltage with a given current threshold.

Using blood pressure monitor on ISS

Background

Below is a summary of the electrical current thresholds:

	Nominal Perception Current Thresholds [V2 9019]	Leakage Currents – Equipment Designed for Human Contact [V2 9023]	Catastrophic Physiological **Startle** Reaction Current [V2 9021]	Catastrophic Physiological Threshold Current **For all situations** [V2 9020]
DC Limits	0.4 mA	Refer to Table 28 below	2.0 mA	40 mA
AC Limits	0.2 mA		0.5 mA	8 mA

*AC = alternating current; DC = direct current ; mA = milliampere

Table 28—Leakage Currents – Medical and Bioinstrumentation Equipment

Maximum Current (mA)				
			Equipment Type	
Body Contact	Frequency	Operating Condition	Isolated Equipment	Non-Isolated Equipment
External*	DC to 1 kHz	Normal	0.1	
		Single Fault	0.5	
	>1 kHz	Normal	f (kHz) x 0.1 (must be ≤ 5)	
		Single Fault	f (kHz) x 0.5 (must be ≤ 5)	
Internal	DC to 1 kHz	Normal	0.01	Not Allowed
		Single Fault	0.05	
	>1 kHz	Normal	f (kHz) x 0.01 (must be ≤ 1)	
		Single Fault	f (kHz) x 0.05 (must be ≤ 1)	

**For DC, there is a small risk of heating and tissue necrosis for prolonged duration of contact.*

From NASA-STD-3001 Volume 2 Rev C [V2 9023]

Some equipment needs to pass small amounts of current through the body to accomplish its intended function, e.g., bias currents in medical monitoring equipment. The amount of current allowed depends on the frequency and whether the part of the equipment contacting the crewmember is isolated from the power source. Examples of isolated equipment are intra-aortic catheters and electrocardiogram (ECG) monitors. Examples of non-isolated equipment are blood pressure cuffs and digital thermometers. These levels of leakage current are consistent with those in *International Electrotechnical Commission (IEC) 60601-1, Medical Electrical Equipment – Part 1: General Requirements for Basic Safety and Essential Performance*, for patient auxiliary and patient leakage currents in isolated (type CF – electrically connected to the heart) and non-isolated (types B and BF – no electrical contact; electronically connected but not to the heart) equipment. These leakage currents are measured across parts applied to the crewmember and from the applied parts to ground.

Background

Physiological Current Limits

Data/evidence to determine the physiological thresholds are from IEC documents along with associated rationale are as follows:

- ***Nominal – Under All Situations*** *These values are below the physiological effect of sensation for the most sensitive members of the astronaut population. This requirement is intended to address typical exposure situations where human contact can routinely occur with conductive housing of electrical equipment and in these situations no perceptible current flow is the design requirement. Typically, NASA engineering teams establish 1 MΩ isolation along with grounding to conductive surfaces with Class H or better bond to prevent current flow through crewmembers*

- ***Catastrophic Hazard Threshold*** *These thresholds are used when a hazard analysis is considering failure scenarios and off nominal events where failures such as electrical short circuits have compromised system isolation and pose a risk of catastrophic electrical shock to the human:*
  - *Catastrophic hazard threshold for all conditions - The current values were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC TR 60479-2, Figure 7). This standard is intended to provide the threshold where additional engineering controls will be required to mitigate electrical shock/physiological effects to the human.*
  - *Catastrophic Hazard threshold specifically for Startle Reaction - The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Table 1). Under certain circumstances such as startle reaction, more restrictive thresholds than the physiological catastrophic limits of the NASA-STD-3001 Volume 2 Rev C [V2 9020] limits above shall be employed in hazard and risk assessments*

- ***Leakage Current Designed for Human Contact*** *These levels of leakage current are consistent with those in IEC 60601-1, Medical Electrical Equipment–Part 1 (see table on the previous page)*

Body Impedance Guidance *– In order to determine appropriate voltage levels not to exceed the current thresholds the following guidance is provided: utilize 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC TR6049-1 to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.*

Reference Data

Data From IEC documents were utilized to set current thresholds.

NASA-STD-3001 Volume 2 Rev C [V2 9020]
Catastrophic hazard threshold for all conditions.

The current values were chosen based on the threshold for maintaining muscle control if shocked to protect 99.5% of the population (IEC TR 60479-2, Figure 7).
The DC component is the x-axis (red arrow), and the peak AC component is the y-axis (yellow arrow). The 99.5th percentile for the most sensitive population (women) was chosen.

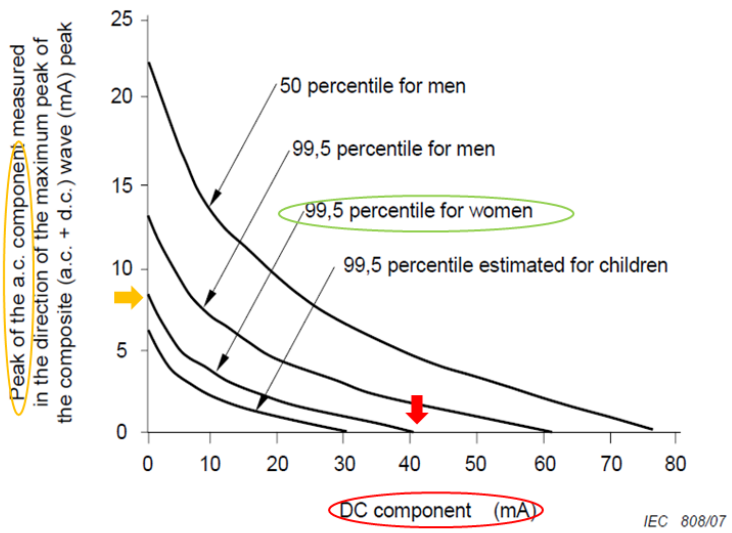

Figure 7 – Let-go thresholds for men, women and children
(IEC) *TR 60479-2, Figure 7*

NASA-STD-3001 Volume 2 Rev C [V2 9021]
Catastrophic Physiological Electrical Current Limits for Startle Reaction

Startle Response is defined as a current level flowing through the body that is just enough to cause involuntary muscular contraction.

The current values were chosen based on the threshold for a startle reaction if shocked (IEC TR 60479-5, Table 1).

Table 1 – Current threshold values for each condition and for long duration

Type of threshold	Current	Current path	mA
Current of startle reaction	a.c.	Hand-to-hand	0,5
		Both-hands-to-feet	0,5
		One-hand-to-seat	0,5
	d.c.	Hand-to-hand	2
		Both-hands-to-feet	2
		One-hand-to-seat	2
Strong muscular reactions	a.c.	Hand-to-hand	5
		Both-hands-to-feet (Note 1)	10
		One-hand-to-seat	5
	d.c.	Hand-to-hand	25
		Both-hands-to-feet	25
		One-hand-to-seat	25
Ventricular fibrillation (Note 3)	a.c.	Hand-to-hand	100
		Both-hands-to-feet	40

(IEC) TR 60479-5, Table 1

Application Notes

Standard Utilization Guidance

The electrical shock standards were written to: (1) Provide parent standard(s) for engineering requirement(s) to limit current flow in routine operations NASA-STD-3001 Volume 2 Rev C [V2 9019 and 9026]; and (2) Provide information for use in determining severity of hazards in all failure/off-nominal situations NASA-STD-3001 Volume 2 Rev C [V2 9020] and for unique situations such as protecting for a startle reaction NASA-STD-3001 Volume 2 Rev C [V2 9021].

Nominal Operations	[V2 9019] is the parent standard that ensure adequate isolation is maintained through the vehicle/operations for routine ops	[V2 9023] is the parent standard that ensure adequate isolation for devices in contact with the human body
Hazard Analysis	Catastrophic Physiological Electrical Current Limits [V2 9020] is the limit that shall not be exceeded under all failure/off-nominal conditions	Catastrophic Physiological Electrical Current Limits for Startle Reaction [V2 9020] is a lower limit that shall be used for unique situation where a startle reaction may be catastrophic

Body Impedance Guidance

In many instances, application of these standards will require the determination of the appropriate body impedance for the calculation of voltage. NASA-STD-3001 Volume 2 Rev C [V2 9022] requires that the 5th percentile is selected in order to protect 95% of the population.

To calculate the appropriate voltage not to exceed the electrical thresholds, the proper body impedance must be selected. Factors that must be considered are the condition of the human/environment (wet vs. dry), AC/DC, voltage level, large/small contact area.

An example utilizing IEC TR 60479-1, Table 3, 850 W represents the 5th percentile of the population for a touch voltage of 125 volts and a large contact area (such as full hand or a surface area of 82 cm^2) in saltwater-wet conditions. (Note Table 10 of IEC 607479-1 may be used for dry conditions). For a catastrophic hazard analysis NASA-STD-3001 Volume 2 Rev C [V2 9020], the maximum voltage would be:

V_{DC} *threshold = 850 W x 40 ma = 34* V_{DC}

Table 3 – Total body impedances Z_T for a current path hand to hand a.c. 50/60 Hz, for large surface areas of contact in saltwater-wet conditions

Touch voltage V	Values for the total body impedances Z_T (Ω) that are not exceeded for		
	5 % of the population	50 % of the population	95 % of the population
25	960	1 300	1 755
50	940	1 275	1 720
75	920	1 250	1 685
100	880	1 225	1 655
125	850	1 200	1 620
150	830	1 180	1 590
175	810	1 155	1 560
200	790	1 135	1 530
225	770	1 115	1 505
400	700	950	1 275
500	625	850	1 150
700	575	775	1 050
1 000	575	775	1 050
Asymptotic value = internal impedance	575	775	1 050

NOTE 1 Some measurements indicate that the total body impedance for the current path hand to foot is somewhat lower than for a current path hand to hand (10 % to 30 %).

NOTE 2 Due to low skin impedances in this case it may be assumed that Z_T depends little on the duration of current flow; Z_T approaches the internal body impedance Z_i.

NOTE 3 For the standard value of the voltage 230 V (network-system 3N ~ 230/400 V) it may be assumed that the values of the total body impedance are the same as for a touch voltage of 225 V.

NOTE 4 Values of Z_T are rounded to 5 Ω.

Back-Up

Major Changes Between Revisions

Original → Rev A

- Updated information to be consistent with NASA-STD-3001 Volume 1 Rev B and Volume 2 Rev C.

Referenced Standards

NASA-STD-3001 Volume 2 Revision C

[V2 9019] Nominal Physiological Electrical Current Limits Under nominal situations (routine human contacts to conductive housing), the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 0.4 mA for Direct Current (DC) and ≤ (less than or equal to) 0.2 mA peak for Alternating Current (AC).

[V2 9020] Catastrophic Physiological Electrical Current Limits for all Circumstances The program shall limit the electrical current through the crewmember to ≤ (less than or equal to) 40mA for DC and ≤ (less than or equal to) 8 mA peak for AC to avoid catastrophic physiological effects to the crewmember.

[V2 9021] Catastrophic Physiological Electrical Current Limits for Startle Reaction During critical operations where a startle reaction is possible, the program shall limit electrical current through the crewmember to ≤ (less than or equal to) 2 mA for DC and ≤ (less than or equal to) 0.5 mA for AC to avoid potentially catastrophic conditions.

[V2 9022] Body Impedance for Voltage Calculations Utilizing Electrical Current Thresholds The program/project shall use the 5th percentile values for the appropriate conditions (wet/dry, AC/DC, voltage level, large/small contact area) from IEC 60479-1, Effects of current on human beings and livestock - Part 1: General Aspects, to determine the appropriate body impedance to calculate the voltage associated with any current limit analysis.

[V2 9023] Leakage Currents – Equipment Designed for Human Contact For equipment such as bioinstrumentation and medical devices, that are specifically designed to contact the human body, electrical leakage currents caused by contact with exposed surfaces shall be kept below the levels specified in Table 28, Leakage Currents-Medical and Bioinstrumentation Equipment.

Reference List

Electrotechnical Commission (IEC) Documents https://standards.iteh.ai/

1. IEC TR 60479-1, Effects of current on human beings and livestock – Part 1: General aspects, 4th edition, 7/2007
2. IEC TR 60479-2, Effects of current on human beings and livestock – Part 2: Special aspects, 3rd edition, 5/2007
3. IEC TR 60479-5, Effects of current on human beings and livestock – Part 5: Touch voltage threshold values for physiological effects, Edition 1.0, 11/2007
4. IEC 60601-1, Medical Electrical Equipment–Part 1, Edition 3.1, 10/2013